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Three-Dimensional Description of the Stratospheric Polar Vortex

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Abstract

This paper aims to notify a helpful tool for describing the complexity of the stratospheric polar vortex. The preparation of the three-dimensional picture of the vortex is based on the analysis of the potential vorticity evaluated on isentropic surfaces. It offers the possibility to describe the polar vortex in its vertical and horizontal shape.

Zusammenfassung

Dreidimensionale Darstellung des polaren Stratosphärenwirbels

Mit dieser Arbeit soll auf ein Analyseverfahren hingewiesen werden, welches die Darstellung der Komplexität des stratosphärischen Polarwirbels ermöglicht. Die Erstellung des dreidimensionalen Bildes des Wirbels basiert auf der Analyse der potentiellen Wirbelstärke auf isentropen Flächen. Es bietet die Möglichkeit der Darstellung des Polarwirbels in seiner Gesamtheit.

1 Introduction

The stratospheric polar vortex is a highly complex phenomenon. Particularly for the northern hemisphere winter it shows strong variability, not only on an interannual timescale but also during single winters. A major stratospheric warming event, where the polar vortex can be destroyed within several days, is one of the most impressive dynamical processes in the middle atmosphere of the earth. The understanding of this variability and the related processes is of importance for the comprehension of the associations between dynamical and chemical processes in the middle atmosphere. The observed ozone variations in the lower stratosphere, for instance, can be explained only if the meaning of these processes is clear. The quantification of the relative contribution of dynamics and chemistry to the observed low ozone concentrations is still under debate.

A lot of questions concerning the dynamical processes connected with the polar vortex are still open, particularly exchange and transport processes at the edge and the inner part of the vortex (see e.g. Randel, 1993).

This paper aims to present a possibility to display the stratospheric polar vortex in its full three-dimensional (3-d) structure. A 3-d perspective of the polar vortex should help to get a better impression of this phenomenon.

2 Analysis

The preparation of the 3-d perspective of the stratospheric polar vortex is based on the analysis of the hemispheric potential vorticity evaluated on isentropic surfaces (e.g. McIntrye and Palmer, 1983):

$$P = -g \cdot (\zeta + f) \cdot \frac{\partial \Theta}{\partial p}, \qquad (1)$$

where Θ is potential temperature, ζ is relative vorticity, $g = 9.8 \, ms^{-2}$ is the acceleration of gravity, and f is the Coriolis parameter. Following Dunkerton and Delisi (1986) a normalization factor is introduced

$$\tilde{P} = \frac{P}{g \left| \frac{\partial \Theta_0}{\partial p} \right|}, \qquad (2)$$

where $\partial\Theta_0/\partial p$, the static stability, is based on values of the standard atmosphere. The transformation of P into $\tilde{P}$ is necessary to define one threshold value describing the boundary of the polar vortex which is valid for all analysed heights.

For this presentation $\tilde{P}$ is calculated by using ECMWF data (potential vorticity) of January 27th, 1993. The horizontal resolution of the data corresponds to $2.5° \cdot 2.5°$. Seven isentropic levels are used for the preparation of the 3-d picture: 350 K, 380 K, 400 K, 435 K, 475 K, 550 K and 700 K which span over the altitude range from approximately 10 to 30 km above sea surface. Unit of the quantity calculated by using (2) is s^{-1} (vorticity unit).

3 Results

Figure 1 shows a conventional picture of the potential vorticity on the 475 K isentropic surface which is used to describe and to discuss the dynamical structure of the vortex, e.g. the position of the edge of the vortex. Figure 2 is the result of a composition of the potential vorticity maps for the isentropic levels 350 to 700 K. The threshold value of P shown here conforms to the region of strong gradients of P. The value is chosen to be $\tilde{P} = 1.9\ s^{-1}$, as proposed by Manney and Zurek (1993), which corresponds to $P = 39.1 \cdot 10^{-6}\ Km^2\ kg^{-1}\ s^{-1}$ for the isentropic level 475 K.

The appearance of the edge of the vortex can be clearly recognized, for instance the groove structure and a dissociate structure from the vortex. The bottom of the vortex near the tropopause indicates a pluglike appearance.

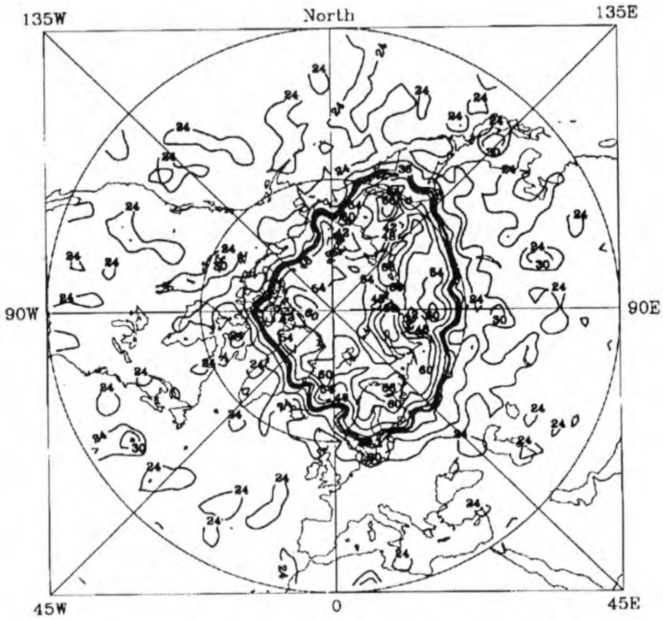

Figure 1 Potential vorticity evaluated on the 475 K isentropic surface near 65 hPa (approx. 19 km) for January 27th, 1993. Contour lines between 24 and 66 are indicated ($\Delta = 6$). The heavy line indicates the 39.1 contour. Units are $10^{-6}\ Km^2\ kg^{-1}\ s^{-1}$.

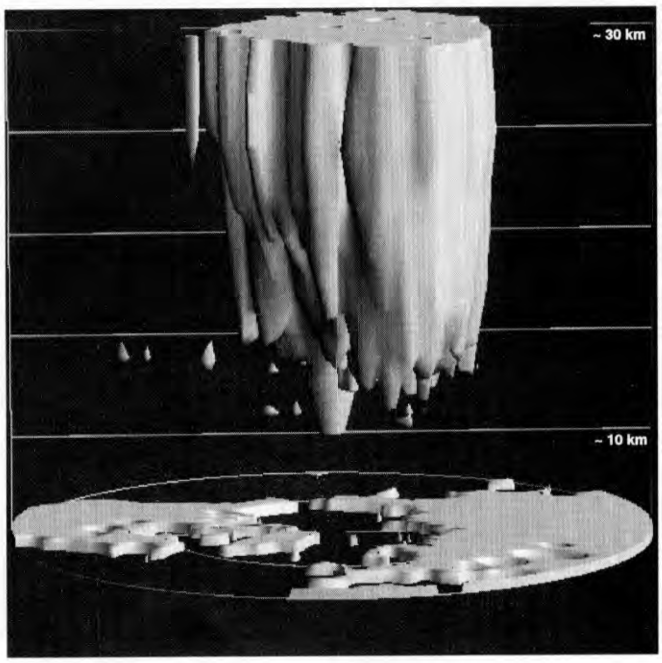

Figure 2 Three-dimensional presentation of the stratospheric polar vortex for January 27th, 1993. The vortex edge is prescribed by the $1.9\ s^{-1}$ contour of $\tilde{P}$. Latitude circles are shown at 30° and 60° N, the continents are indicated with their coastlines. The vertical coordinate is potential temperature Θ, with $350\ K \leq \Theta \leq 700\ K$, approximately 10 to 30 km height.

4 Discussion

The 3-d view of the polar vortex enables an *additional* insight in the structure of the polar vortex. The exhibition of the vortex as a whole helps to get a better impression of the phenomenon itself, it helps to recognize complex structures of the vortex edge. This 3-d diagnosis of the vortex do not supersede other analysis procedures, it should be added to them.

It should be mentioned that the selection of the contour value (here 1.9) is critical. The choice of another value (1.8 or 2.0) can change the result, the appearance of the polar vortex. Such 3-d plots should be taken as an expedient to learn more about the complexity of the polar vortex but not as a single instrument for analysing the dynamics of the vortex. The presented method offers interesting perspectives for further animations: ECMWF data which are available every 6 hours or model data with high time resolution can be used to make video films showing the development of the stratospheric polar vortex, for instance during a major stratospheric warming event.

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